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Recapturing fish escapes from coastal farms in the western Mediterranean Sea: Insights for potential contingency plans

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ABSTRACT

Escape incidents of farmed fish involve economic losses to fish farms, interactions with local fisheries and environmental impacts to coastal ecosystems. More attention should clearly be paid to preventive measures. It is also essential to develop and establish contingency plans in case of escapes, to mitigate potentially negative socioeconomic and environmental impacts. Three mark-and-recapture experiments simulating escape incidents of sea bass (N = 1000 ind.), sea bream (N = 1000 ind.) and meagre (N = 1000 ind.) were carried out at three coastal fish farms located along the Mediterranean Coast of Spain. First, targeted experimental fishing trials in collaboration with artisanal netters were attempted at each location as potential fast-response contingency plans for recapturing escapees. Targeted fishing was successful on meagre (N = 38 ind., CPUE: 2.2 ind 10 m^{-2} h^{-1}) and sea bream (N = 8 ind., CPUE: 1.3 ind 10 m^{-2} h^{-1}), while no sea bass were recaptured. Secondly, recaptures reported from local fishermen (professional and recreational) during the study period were also considered. Altogether, total recapture rates were similar among the three species (sea bass: 5.4%; sea bream: 7.1%; meagre: 8.7%), although the spatial and temporal observations of recaptures varied among species. Recreational fishermen were the only contributors, recapturing 54 tagged sea bass (angling: 85%; spear-fishing: 15%) in mainly shallow coastal waters and about three km distance from the fish-farm during the weeks after release. A total of 71 escaped sea bream were recaptured by both recreational and artisanal fishermen, contributing similarly (recapture rates: 47.9% and 40.8% of total, respectively). Most sea bream recaptures were during the first nine days after release (86% of total recaptures), mainly near the farm facilities (< 3 km). The bulk of meagre recaptures were during the first two days after release (> 95%), mainly by experimental and artisanal netting (38 and 47 individuals respectively) again near the facility. In parallel, an underwater visual census was carried out at coastal locations and Natura 2000 sites in each study area, to assess the presence of escapees in marine habitats of special interest. Neither escaped sea bass nor escaped meagre were observed during underwater surveys, and only three tagged sea bream were found together at artificial reefs. Given that recaptures of tagged fish differed among fish species and fishing techniques following simulated escape incidents at W-Mediterranean coastal facilities, diverse potential contingency plans are here discussed.

1. Introduction

Escapes from off-shore and coastal fish farms have been one of the major problems for the farming industry during the last few decades (Holmer, 2010). Considered one of the main challenges in the production process, escape events involve not only financial losses to fish farms but also environmental impacts on coastal ecosystems (Naylor et al., 2005; Jensen et al., 2010). Escape incidents are caused by technological and/or operational failures, such as cages broken during storms, appearance of holes from wear and tear including fish biting the net, and operational accidents during farming manoeuvres (Jackson et al., 2015). Large-scale fish farming in the Mediterranean Sea was developed in the early nineties. Today, European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) aquaculture is an important source of income in many Mediterranean regions (Trujillo et al., 2012), while meagre (*Argyrosomus regius*) is still an emerging species for Mediterranean aquaculture (Duncan et al., 2013). Nevertheless, some studies have revealed serious potential ecological implications of escapees in the Mediterranean, such as competition for local resources, spread of diseases and parasites, genetic interactions, and in general,

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destabilization of the food chains in coastal marine ecosystems (e.g. Arechavala-Lopez et al., 2011, 2012, 2013, 2014, 2017a; Šegvić-Bubić et al., 2011, 2017a; Valero-Rodriguez et al., 2015). At the population level, the mere presence of escapees in coastal waters might increase the proportion of immature fish, modifying the natural population structure of the species (Dimitriou et al., 2007). Consequently, the effects of escape incidents can also be monitored in local fisheries, noting a direct increase of escaped individuals within their catches (Toledo-Guedes et al., 2009, 2014a,b; Arechavala-Lopez et al., 2015; Izquierdo-Gomez and Sanchez-Jerez, 2016; Izquierdo-Gomez et al., 2016, 2017). All these effects will depend on the magnitude and frequency of the escape, reaching maximum levels in the event of massive and recurrent escapes (Toledo-Guedes et al., 2014a,b; Izquierdo-Gomez and Sanchez-Jerez, 2016; Izquierdo-Gomez et al., 2016, 2017). Leading fish-producing countries such as Norway, Canada, USA, Scotland or Chile have already developed specific regulations addressing fish escape events, which are annexed in the general legal aquaculture framework (Arechavala-Lopez et al., 2017b). Surprisingly, despite substantial fish production within the Mediterranean, none of the coastal countries have legally addressed the socio-ecological issues arising from escape events. For these reasons, it is highly important to develop contingency plans in case of escapes, which will help to mitigate the possible negative socioeconomic and environmental effects, thus enhancing sustainable management of coastal areas (Izquierdo-Gomez and Sanchez-Jerez, 2016). Therefore, through mark-and-recapture experiments simulating escape incidents at sea bass, sea bream and meagre farms, the aims of this study were to: i) attempt experimental fishing for the first time, implementing short term fast-response protocols for recapturing escapees in collaboration with artisanal fishermen; ii) examine the longer-term contribution (on a scale of weeks) of local fisheries recapturing tagged fish; iii) assess the recapture patterns of escapees through experimental fishing actions and fishermens' captures; and iv) detect the presence of tagged individuals in marine habitats of special interest (i.e. Natura 2000 Special Protection Areas) located near the fish farms, by underwater visual census. All this information will help decision makers develop contingency plans to mitigate the negative effects of fish escapes from Mediterranean farms in the coming years.

2. Material and methods

2.1. Study area

The study was carried out in the western Mediterranean Sea in three regions of the SE coast of Spain: Málaga, Almería and Águilas (Fig. 1). In Málaga, the first studied fish farm annually rears about 1200 tonnes of fish (sea bass and sea bream) in 24 open-sea cages at 1.3 km from the coast line. The commercial fleet in Málaga is composed of 13 artisanal trammel-netters, 13 bottom-trawlers and 40 purse-seiners. In Almería, the second studied fish farm is located near Aguadulce, where about 2500 tonnes of fish (sea bass and sea bream) are annually reared in 30 open-sea cages at 0.5 km from the coast line (Fig. 1). The commercial fleet in Almería has 28 artisanal trammel-netters, 46 bottom-trawlers, 32 purse-seiners and nine long-liners. The third studied fish farm is near the town of Águilas, where 600 tons of fish (sea bream, sea bass and meagre) are farmed annually in 18 open-sea cages at 0.7 km from the coast line (Fig. 1). In Águilas, 20 artisanal vessels (trammel-netters and traps), 10 trawlers, three purse-seiners and two long-liners operate commercially. Recreational fisheries (angling and spearfishing) are also widely distributed within the studied areas, co-existing with small-scale coastal fisheries and fish farm facilities but also spread along the coastline. Indeed, small-scale fishing and recreational vessels usually operate in areas adjacent to the fish farm in the three study areas. In addition, Natura 2000 Special Protection Areas (SPAs; European Council Directive 92/43/EEC) can be found in the three study areas (Fig. 1).

2.2. Simulating escape events

Three mark-and-recapture experiments were carried out to study the landing dynamics of escapees, namely farmed sea bass in Málaga, sea bream in Almería and meagre in Águilas. A total of 1000 fish per experiment (i.e. 1000 fish per species and one species at each farm locality) were tagged with external T-bar anchor tags (Hallprint Ltd., Victor Harbour, South Australia) and released at farm facilities where they were reared, simulating three different escape events (Table 1). Tagged fish remained in a cage for 24 h before the experiment started, to control for mortality and ensure that fish escaped as quickly as possible to simulate a massive escape instead of a leakage-like event. Tagged fish species were released on different dates: sea bass on the 5th of August 2014 in Málaga, sea bream on the 30th of September 2014 in Almería, and meagre on the 21st of October 2014 in Águilas, Murcia. T-bar anchor tags were inserted on one side near the dorsal fin base of the fish, which enable individual identification in case of recapture. This tagging method has also been successfully applied in previous studies on sea bass (Grati et al., 2011; Arechavala Lopez et al., 2014), sea bream (Sánchez-Lamadrid, 2001, 2002, 2004; Arechavala-Lopez et al., 2012) and meagre (Gil et al., 2014a,b; 2017). In order to avoid an abnormally greater fishing effort around the farms, leading to potentially increased recapture success, only the fishermen involved in the fishing actions were warned about the experimental escapes. Once the fish were released, information on the tagging programme (poster and leaflets) was sent to recreational and professional fishermen's associations, ports, fishing stores and fishery research centres along the coast of the study areas. When a tagged fish was recaptured, the fishermen provided information on its identification code, date of recapture, fishing method and recapture point (GPS coordinates if possible). All handling and tagging was carried out according to the Spanish regulation for the treatment and welfare of animals (Real Decreto 53/2013, published in BOE num. 34, 8th February 2013).

2.3. Experimental fishing and fishermen contributions

The fishing actions, as part of a future contingency plan under development, consisted of experimental one-day fishing trials conducted in close collaboration with local professional fishermen at each locality, in order to recapture experimental escapees (Fig. 1). Based on their experience, one fisherman per location was requested to select the fishing nets with regard to the target escaped species, and also where to set the net for successful recaptures. In Málaga, a nylon fishing net (400 m length and 1.4 m height) was set between the shore and the fish farm on the day after the simulated escape event ($\sim$24 h), early in the morning for 12 h. In Almería, a trammel-net (400 m length and 1.5 m height) was deployed the third day after the escape event (72 h), next to the farm along the shore sides of the facility, fishing over 10 h approximately in the morning. The time-lag on this action with respect to the others was due to a delay in legal permission. In Águilas (Murcia), a trammel-net (800 m length and 1.8 height) was deployed at dawn near the farm, covering its shore-sides the day after the escape ($<$ 24 h), fishing for 12 h approximately. Recapture patterns were firstly evaluated for each species through the accumulated number of fish recaptured per day during the study period, and also regarding the daily recapture using each type of fishing gear and the distance between capture and release site (farms). Targeted captures from experimental fishing were firstly analysed separately from other fishing methods. Given that experimental nets were different between the sampling areas, targeted captures were standardised according to net size and fishing hours (i.e. CPUE: capture per unit of effort; units: number of captured individuals 10 m^{-2} h^{-1}). Then, targeted captures were clustered together with catches from artisanal netters to analyse recaptures according to type of gear. Recapture rates were estimated for targeted fishing (T) and all recaptures together (targeted and untargeted fishing).